Work-in-Progress – Incorporating Open-Ended Design Projects in a First year Engineering Course

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***Abstract* - A first year engineering program with a multidisciplinary introduction to engineering course is developing an open-ended design project. This course is designed to teach the basics of each engineering discipline through labs, lectures, and a course project. It is a one semester course offered in the fall and spring, and all engineering majors are required to take it. Around 300 students take the course each semester, and they are broken into 21 sections with a maximum of 18 students per section. The current project offerings include robotics courses, building design, and programming autonomous train control. The goal of adding an open-ended design project is twofold: 1) to give students the chance to explore their own interests and 2) to provide motivated students with an appropriate challenge for their skill level. Adding an open-ended project to the first year engineering experience is a common practice, but several issues must be considered to provide a fair experience to all students. Plans for deploying a pilot section in the fall of 2016 have been made. Based on the success of the pilot section, open-ended projects may be offered in more sections. The authors seek the insight from the first year engineering community to create the most effective version of this pilot section.**

Index Terms – Invention, innovation, and entrepreneurship; Makerspace; Multidisciplinary; Open-ended design project

INTRODUCTION

Many first year engineering courses have design projects with predefined tasks. This curriculum can cause students to feel obligated to finish a project due to external motivations of passing the course. Allowing students to generate project ideas can increase motivation to complete the project and their interest in engineering. This transition from extrinsic to intrinsic motivation has been used to improve retention of engineering students during the first year. Experimenting with open-ended design projects and project choice has been common in first year programs over the last two decades.

Open-ended design projects can help address ABET students' outcomes: 1) an ability to design a system, component, or process to meet desired needs; 2) an ability to identify, formulate, and solve engineering problems; and 3) a knowledge of contemporary issues. In addition, open-ended design addresses the request from industry professionals to prepare students to identify problems rather than just solve them. In engineering education this has been practiced by switching to process focused design rather than product focused design. A prevailing opinion in recent years is that competency in a systematic problem solving method is more important than producing a final product.

LITERATURE REVIEW

Recent literature has indicated methods for adding open-ended projects to an introduction to engineering course. Two focuses have been the level of definition of a project and freedom of choice for the topic. Less guidance gives students a chance to practice identifying problems and gives them ownership of the project. This type of learning has been classified as Model Eliciting Activities (MEA) because students focus on procedure rather than the final product [1]. Student engagement in the project increases with their ownership of the project – the motivations for completing the project are now intrinsic rather than extrinsic [2]. Allowing students to complete a project they are excited to work on results in greater interest in engineering.

I. Instruction, Support, and Materials

In order to prepare students for open-ended projects, many courses emphasize or add new training. The most common emphasis is some variation of the engineering design process. This includes brainstorming, finding a solution, prototyping, testing, and revising iteratively [2]. Others have included an overview of design techniques such as the design process, rapid prototyping, ethics, user-focused design, ergonomics, and human-computer interaction [3]. Courses have also instructed students on the process of fabrication, time and resource management, and block diagrams [4]. This training is often supplemented by support for specific tools.

Support for open-ended design is composed of three major components: 1) mentors, 2) instruction on equipment and software, and 3) space. In order to properly prepare teaching assistants (TA) for open-ended projects it is advised to provide TAs with training on pedagogical knowledge and give them feedback on an example of their ability to assess students [5]. Students require specific training on computer-aided design (CAD) software (e.g. AutoCAD, Inventor, SOLIDWORKS), programming for microcontrollers (e.g. Arduino), and project management software (e.g. Microsoft Project) [2],[6]. Providing a space where TAs can deliver supplemental instruction on specific skills and a central location for equipment and materials can improve student success [7]. Support should be specialized to equipment, materials, and tools used for the projects.

First year courses have experimented with providing tools and components to students and building makerspace labs. In general, students are expected to learn electrical and mechanical engineering skills by building a programmable device. Arduino, an open-source electronics platform, has been adapted by many courses because it is easy to learn, cheap, and widely supported. Some courses provide students with a custom assembled kit, while some have them purchase a pre-selected kit [7]-[8]. These kits typically include simple sensors such as photo- or temperature- sensitive resistors; infrared (IR) or ultrasonic range finders; and actuators such as motors, fans, LCD displays, and speakers/buzzers. They also include accessories: cables, wires, breadboards, buttons, LEDs, and resistors [6],[8]. Collaborative labs have hand tools, electrical tools (soldering irons, multimeters), and rapid prototyping equipment (3D printers, laser cutters) [7].

II. Project Topics

Open-ended project topics by nature can vary widely based on the focus of the course. Three common themes in first year engineering courses are service-learning such as Engineering Projects in Community Service (EPICS), research such as Vertically Integrated Projects (VIP), and entrepreneurship such as the Entrepreneurship and Innovation Program (EIP) [9]-[12]. The specific topics often involve popular real-world problems. A representative list of topics include alternative energy, systems design, humanitarian issues, engineering in the arts, entrepreneurship, and environmental problems [13]. The number of potential topics make it important to have a generalized framework for project requirements and grading.

III. Project Requirements and Grading

Many courses have general expectations or deliverables to help students through the design process. One course requires turning in a product description, list of user needs, product specifications, 3D model drawing with dimensions, and a user evaluation plan [3]. Another requires documentation of simulation, CAD drawings, a prototype, 3D printed case, and testing [4]. These requirements are translated into a rubric.

It is critical that students receive formative assessment – feedback gives students a chance to make corrections before they have progressed too far in a wrong direction. A model for feedback involves surveying the project, asking probing questions, guiding teams, and confirming when they have succeeded [14]. For summative assessment, it is common to create a rubric for deliverables or the engineering design process [15]. Weighting should be used to highlight more important components of the project (i.e. a physical prototype is more important than the 3D printed case) [16].

IV. Potential Problems

Open-ended projects can lead to problems based on project selection and the logistics of implementation. Anxiety about choice of the project can stem from regret, opportunity costs, expectations, and self-blame [17]. A scale has been used to classify the range of student capability: failing to start when they are overwhelmed, getting stuck on a small problem, to following a systematic, linear approach [18]. Logistical issues for these projects include a burden on professors to know too much, the limited time available in a course to complete a project (let alone define one), and teaming students with similar interests [19]. Despite these issues most studies indicate positive outcomes for open-ended projects.

V. Outcomes of Open-Ended Design

A majority of studies have shown that open-ended design leads to improved engagement, interest, and retention in engineering [8],[17],[20]. Studies have also shown that problem formulation practice improves problem solving [2]. Students perform just as well with ill-defined problems as well-defined problems, and ill-defined problems lead to greater focus on user needs [3]. A critical component to quality problem solutions is an effective team [21]. However, when given pre-selected options in addition to a free choice topic a minority of students select the choose-your-own option [17]. A small number of motivated and qualified students may feel comfortable defining their own problem.

METHODS

A pilot section of a first year course is being tested by adding an open-ended project. The course has three defined projects in robotics, programming, and building design. Encouraged by the development of the university's makerspace and current trends in first year engineering education, this pilot section will be given freedom to choose their design project. The course will teach students about contemporary issues in engineering and provide resources for prototyping, mentors, training, and makerspace facilities to assist students. The intent is that students will select a project, or problem formulation, reviewed by faculty, which can be reasonably completed during the semester using the available tools. Should this not be possible within this course, plans should be provided for completion in the future. End user needs and specifications for the future work should be given.

The research question regards the most effective way to implement open-ended design projects and evaluate the performance of students. Surveys throughout the semester on student opinions of their project, teamwork, and studying engineering will be used. The researchers plan to perform a longitudinal study of retention and performance of students in the pilot section. A framework for adding an open-ended design project is based on practices described in the literature and is documented in the discussion section of this paper.

DISCUSSION

The pilot section of the first year engineering course will use only open-ended projects with free choice. One lab will be added to introduce Arduinos and sensors. The plan addresses: instruction and materials, project requirements, and logistics.

I. Instruction and Materials

An essential component of first year engineering is instruction on the design process, which will be emphasized to a greater extent for brainstorming – both for problems and solutions. A lecture on current topics will help guide students through engineering problems such as the National Academy of Engineering Grand Challenges for Engineering, Internet of Things, Maker Movement, and university research thrusts. In-class discussion will focus on tractable problems for first year students such as solar energy, urban infrastructure, clean water, wearable technology, autonomous vehicles, and smart buildings. Students will also be instructed on the Lean Startup methodology to frame projects in a viable economic context. Technical training in the course will focus on programming, microcontrollers, sensors, and 3D modeling.

The materials provided for the special section aim to bring together all disciplines. Arduinos are inherently electrically focused, but the instructors hope for the basic programming and wiring to be simplified so that the smart technology applications are the focus. Table I lists default materials that will be provided in the custom kits. Each team will receive this kit in the third week as they perform the new lab. Table II lists potential materials that can be purchased based on the needs of the project and justification of the cost.

TABLE I
PROTOTYPING MATERIALS IN DEFAULT STUDENT KIT

Part	Description
Arduino	Programmable microcontroller with I/O pins
Breadboard	Prototyping board for connecting electronics
Photocell	Light sensitive resistor
Transistors	Electronically controlled switches
Accelerometer	Triple axis (x, y, z) motion detector
Flex sensor	Bending sensitive resistor
Temperature sensor	Outputs voltage proportional to ºC temperature
IR sensor	Outputs voltage proportional to IR light
Pushbutton	Momentary mechanical switch
Accessories	USB cable, jumper wires, resistors, kit box

TABLE II
ADDITIONAL RECOMMENDED MATERIALS BASED ON NEED

Part	Description
LCD screen	Full 16-bit color display
GPS breakout board	GPS chipset and antenna
Raspberry Pi 3	Single board computer with Wi-Fi and Bluetooth
Accessories	DC power supply, DC level shifter, micro SD card
Gas sensors	Methane, liquefied petroleum, hydrogen, carbon monoxide, alcohol
Weather sensors	Humidity, barometric pressure, soil moisture, altitude, UV light
Biometric sensors	Fingerprint scanner, pulse
Actuators	DC motor, stepper motor, pump, solenoid, relay
Imaging and sound	Camera with controller connection, speaker, buzzer
Power generation	Solar panel, inductive charging, piezoelectric

It is important to provide students with space to work on their projects and receive additional guidance. The first year course is developing a prototyping space with common equipment seen in makerspaces. This space will also have teaching assistants to help students with 3D modeling, 3D printing, circuit wiring, coding, and prototyping. The university is constructing an advanced makerspace and students will be encouraged to use this additional equipment.

II. Project Requirements

The expectations for the open-ended project will be similar to those found in literature. First and foremost, students must develop a physical prototype. This prototype will require some programming with documented code, 3D prints with CAD files, and measurement testing with an algorithm for inputs and outputs. The first weeks of the semester will be dedicated to brainstorming project ideas and forming groups. Each group of three students will generate two or three ideas to present in class as a proposal. Instructor approval will be required before teams can work on the project. A constraint on project ideas will include a multidisciplinary nature of the topic. Students will be given suggestions for the form of their prototypes such as mobile applications, smart devices, sensors, robotic parts, lab equipment, or measurement tools.

III. Logistics

Two primary considerations for the course are how to select students for the pilot section and how groups will be formed. First year advisors are distributing a call for applications to admitted students. This solicitation will be sent out to the top 100 students based on admission criteria. An application will identify interest in taking the pilot section of the course and prior technical experience. Once the students have been selected for the section, professors will decide whether the teams should be pre-defined or students should be given the freedom to choose their partners.

Other major considerations for the special section are mentorship and assessment for the open-ended design projects. The first year engineering course has many teaching assistants who can be matched with teams based on interest and experience. These mentors will help ensure that the open-ended design projects stay on track and are completed successfully – even if the success is not what the teams initially intended. The assessment of the course projects will focus on the process, not the product. The project will be evaluated based on technical development of the product and consumer focused design. Specific rubrics are still being developed by the professors of the course.

CONCLUSIONS AND RECOMMENDATIONS

Many first year engineering courses are experimenting with open-ended design projects to adjust for the demand of project-based curriculum in engineering education. With the advice from the first year engineering community, the first year engineering program of this study wishes to answer questions about best practices for open-ended design project implementation. Several previous studies have addressed many aspects of developing such a project. This study aims to collect this information and generate a standard process for adding open-ended design projects with free choice to the first year engineering experience.

There are many aspects of an open-ended project that can be treated in a variety of ways. Specialized instruction, materials, project expectations, and logistical issues need to be considered. The researchers hope to be invited to a round table discussion at FYEE to incorporate input from the first year community into the design and analysis of the new open-ended projects for the pilot section of this course.

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